Physics 325:Lab # 3 Telescopes

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1 Objective

To construct refracting and reflecting telescopes and determine the magnifying power of each.

2 Apparatus

achromatic objective lens, parabolic objective mirror, mounts for each, Kellner eyepiece 12.5x, homemade reticle, screens, metre stick, ruler

3 Theory and References

You probably want to look at Pedrotti[3] to fill in any details and diagrams. Try pp. 37-39, 71, 75-78,82-89. Also pp. 54-57 if you want more information about field of view but it probably isn't necessary.

The *relative aperature*, A, of a lens or lens combined with an aperature is related to its focal length f and diameter D

$$A = \frac{f}{D} \tag{1}$$

This quantity is also called the *f-number* or speed of a lens. The higher the *f-number* the slower the lens. The irradiance at the image is now

$$E_e \propto \frac{1}{A^2} \tag{2}$$

Suppose that you have an object of height h_o above the central axis and an image with height h_i. If $h_i < 0$ then we will have an *inverted* image and the *lateral magnification* m will be negative. In summary

$$m \equiv \frac{h_i}{h_o} = -\frac{s'}{s} \tag{3}$$

There are times however when viewing virtual images through instruments that *angular magnification* M is the more appropriate description of "the" magnification. Suppose that you try and make the image of an object as large as possible on your retina: you bring the object as close as possible. Eventually your eye can no longer focus (try it with your finger or a textbook). For most people this *near point* is roughly 25 cm. So if the object had a height of h_o then the angle subtended by the object would be $\tan^{-1}(h_0/25)$ (h_o in units of cm). Now use a convex lens as a simple magnifier. If you move the object to $s = f$ then you can form a virtual image at $s' = -\infty$. [1] If α_o is the angle subtended by the object when viewed by the unaided eye and α_M is the angle subtended by the image then

$$M \equiv \frac{\alpha_M}{\alpha_o} = \frac{\tan^{-1}\{h_i/(-s')\}}{\tan^{-1}(h_o/25)} \tag{4}$$

For some reason I always find the next step difficult. How tall is an image at "infinity"? Well, if it is truly at infinity then it has an infinite height. Rats! But the equation calls for the ratio of the two so that might be finite. In fact we can use equation 3 to give the ratio as h_o/s which is h_o/f in this case.

$$M = \frac{\tan^{-1}(h_o/f)}{\tan^{-1}(h_o/25)} \approx \frac{25}{f} \tag{5}$$

(I have used the small angle or paraxial approximation.) The Kellner eyepieces that you use in this lab are "suped up" magnifiers where efforts have been made to reduce aberrations (chromatic in particular) and to match with the size of the pupil in your eye.

When you actually make measurements in the lab using a telescope and the object is far away ($s = \infty$) you can actually measure α_o by using a tape measure (for s) and a ruler (for h_o). Values are given for the angular magnification of a distant object as

$$M = \frac{\alpha_M}{\alpha_o} = -\frac{f_o}{f_e} \tag{6}$$

where these are angular sizes of image, object, focal length of the objective, and the front focal length of the eyepiece. To get a value for α_M you need some kind of angular scale. If the real image has a lateral size of 2 mm and is placed at the focal plane of the eyepiece then in the paraxial approximation $\alpha_M = 0.2/\text{ffl}$ [2]

4 Safety and Protocols

Again no lasers with this lab. Please be careful with the lenses and mirrors. Make sure they are solidly mounted and not in places where they will fall. Do not touch the surfaces with your fingers.

[1] Or a real image at $s' = \infty$ which, believe it or not, is the same thing from the point of view of the rays. Just a parallel bundle.

[2] When you combine to lenses with a finite separation, as is done in the Kellner eyepiece, you distinguish between a *front focal length* that is measured from the *field lens*. An object placed at the ffl will give a virual image at infinity when viewed through the *eye lens*.

5 Procedure/Analysis

As a piece of general advice for this lab put in lots of diagrams to show what you are doing!

1. Mount the objective lens if it has not been mounted already. Keep the plastic washer between the lens and the "nut". Determine the focal length of the lens by the "infinity" method and by imaging a light bulb. The focal length is greater than 300 mm so you will need a bit of room. Measure the diameter of the lens and calculate the relative aperture or f-number.

2. Determine the focal length of the mirror by the infinity method. It has quite a long focal length so you will need some room. Note that you can partially block the incoming light without significantly damaging the image.

3. For each of the above cases make an estimate of the size of the object (h_o) and its distance (s). What is the angle subtended by the object? What is the size of the image on your screen (h_i) and what is s'? What is the angle subtended by the image?

4. Look through the ocular (eyepiece) at objects in the room. What do you see? What can you conclude about the behaviour of the ocular based on this observation? Try to use the ocular as a magnifier. Any luck? Try focussing on the point of a pen or pencil inserted slightly inside the end of the eyepiece. *Estimate* the ffl.

5. This focal plane is where you want to put your *reticle*.[3] What is the line spacing of your reticle? What do you expect the magnification of the reticle to be based on the ffl? (Use formula 5.) Does it agree with the 12.5x listed for the eyepiece? Install the reticle in the eyepiece. Your eye should be able to clearly and easily focus on the reticle lines.

6. Now construct your refracting telescope. Set it up so that the real image of a distant object (a lit up metre stick on the other side of the room) formed by the objective is formed at the ffl. Move the eyepiece back and forth to focus. How many "object" centimetres between the reticle lines? Calculate the actual magnifying power and compare to the predicted value. What is the field of view (in degrees)?

7. Briefly, what are the roles played by the objective and the eyepiece and how do these effect the design? (They are just supposed to be convex lenses right?)

8. Do the same things with a Newtonian reflecting telescope. (See Figure 3-34a of the text.) Also give A for the objective. Why don't you see the blocking mirror?

[3]The reticle appears as crosshairs or a scale in the visual field. If you looked through the telescope of the Millikan experiment the grid was formed by a reticle.